ADAPTATION OF I-TREE ECO TO NEW ZEALAND

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Abstract

Urban trees provide a range of benefits to humanity, known as ecosystem services. The US Forest Service developed a model known as i-Tree Eco for quantifying these benefits and applying dollar values to them. However, i-Tree Eco lacks species- and location-specific information for New Zealand (NZ). This study investigates the applicability and data requirements for using i-Tree Eco to quantify the ecosystem services of urban trees in Auckland, NZ. This included a case-study of 95 trees of 7 species in Wynyard Quarter. Auckland weather and air pollution data were successfully incorporated into i-Tree Eco, and it was found that while the model can currently be used for approximate quantifications, research into species-specific biomass, growth, and leaf area equations would improve the usefulness of the model by providing more certainty on the accuracy of results. Mature trees were found to have much higher rates of pollutant removal and carbon sequestration than immature trees. Valuations of pollutant removal were found to be incomplete, but results suggested a possible pollutant removal value of NZD $246/year total for the 95 trees, primarily from <10 micron particulate matter. Suggestions were made for future research to improve use of i-Tree Eco in NZ.

1. Introduction

Trees provide a wide range of benefits to humanity, known as “ecosystem services” (Millennium Ecosystem Assessment 2005). As the world faces increasing urbanisation of populations (Wu 2008), trees are becoming increasingly relevant in urban environments as a resource to provide benefits to people. Urban trees can reduce pollution, reduce temperature and the urban heat island effect, reduce building energy use (Nowak 2000), intercept rainfall (Xiao *et al*. 1998), and provide direct and indirect economic benefits (McPherson *et al*. 1999). They can also provide improvements to physical and psychological health (Tsunetsugu *et al*. 2013), as well as aesthetic, artistic and recreational benefits (Costanza *et al*. 1997).

Urban trees therefore are a valuable resource; however quantifying these benefits is often difficult, due to the indirect nature of some of their effects (Costanza *et al*. 1997). Costanza *et al*. argue that while some of these services are difficult to accurately quantify, applying economic value to an ecosystem's services to humans aids in understanding the importance of those services. Therefore having the ability to quantify the ecosystem services of urban trees would be useful.

Sensible practices for the management of trees in an urban environment should be informed by quantitative evidence. At present, this information is not available to government and local councils in NZ, despite being of interest to organisations such as Auckland Council (Creagh *pers. comm*. 2013).

In the United States of America (USA), the US Forest Service created a collection of tools to model urban trees collectively known as i-Tree (US Forest Service 2012a, US Forest Service 2013a). These tools can model the ecosystem services provided by these trees, up to the scale of a city’s entire urban forest. One of these components – i-Tree Eco – is used for analysis of urban forests across a range of scenarios and has the potential for use in other parts of the world. Eco was chosen as the focus for this study.

Local tree measurements, pollution and weather information, tree-species-specific growth equations, and pollutant valuations are taken as inputs into i-Tree Eco. It outputs the quantities and associated dollar values of pollutants removed, quantities of carbon stored and sequestered, and data about the health, status and composition of an urban forest (US Forest Service 2012a).

i-Tree Eco’s calculations on the sequestration and storage of carbon by urban trees can be used for carbon accounting to inform emissions trading and targets such as those that were set out in the Kyoto Protocol. Analyses of carbon storage using i-Tree were further investigated in a parallel paper by Dale (2013).

i-Tree Eco was yet to be successfully implemented in NZ prior to this paper (Nowak *pers.*

comm. 2013a). While some species information progress was made by a researcher at the University of Canterbury (Morgenroth *pers. comm*. 2013), the viability of i-Tree Eco for quantifying ecosystem services of urban forests in NZ had not been determined.

i-Tree Eco projects can either be plot-based, where samples are taken across a wide geographic area to establish averages (for example, to analyse a whole city), or a full inventory, where all trees in a specified study area are measured. The former should use upwards of 200 plots (US Forest Service 2012a), however the latter can be performed on a small area, and therefore requires a much smaller investment of time and resources.

Some features of i-Tree Eco are not available to international users, or give results that are not locally applicable. This is because the i-Tree models were developed specifically for the USA. Outputs listed in the i-Tree Eco Manual as being unavailable for international users include: rainfall interception, structural tree value, pest modelling, and energy effects (US Forest Service 2012a).

1.1. Objectives

The objective of this project was to identify the requirements for, and suitability of, implementing i-Tree Eco in NZ. This included locating and collecting all relevant data sources, and determining areas of missing or incomplete data that would limit the accuracy or suitability of using i-Tree Eco in NZ. A specific focus was on quantifying air pollution reduction by urban trees and the NZ dollar valuation of these. Where possible, data sources were sought that could be incorporated into i-Tree Eco by the US Forest Service, for use by subsequent NZ-based projects.

Model feasibility was tested with a case study project on a sample of 95 urban trees in a site in Wynyard Quarter, Auckland, NZ using i-Tree Eco version 5.0. This was a small full-inventory project, as a larger-scale plot-based project was outside the scope of this project, given the available resources.

2. Methodology

To run an international model, the i-Tree Eco model requires (US Forest Service 2012a):

- tree species, or a list of similar trees used as substitutions;
- a full year of local pollution data;
- local weather data;
- data measured from local trees (plot-based or a full tree inventory);
- ideally, species-specific information such as allometric biomass equations that describe the relationships between tree dimensions and carbon storage (these are discussed by Dale 2013).

The procedure for processing of an i-Tree Eco project is to compile all necessary data and then send it to the US Forest Service for processing. Data for the case study project was sent via email to the i-Tree team.

2.1. Tree Species Information

i-Tree Eco maintains a species database, which was searched for tree species found on site. Where tree species did not have an entry in the i-Tree Eco database, a related species in the database was chosen as a substitute (details of substitutes in Results, section 3.4).

2.2. Pollution Data

i-Tree Eco requires a full year of hourly data observations for air pollution data. These data were obtained from Auckland Council (Bouzonville *pers. comm*. 2013), who maintain a network of air quality monitoring stations around the city, tracking concentrations of pollutant gases and particulate matter of <10 and <2.5 micron diameter (PM_{10} and $PM_{2.5}$ respectively). One of the stations was located on the National Institute of Water and Atmospheric Research (NIWA) building in Khyber Pass, Newmarket and was used where possible due to its central location, for CO, NO_2, and PM_{10}. Sites in Takapuna ($PM_{2.5}$), Musick Point (O_3), and Penrose (SO_2) were used where the Khyber Pass site lacked data, or did not have records for a specific type of pollutant. All air pollution data was for the year 2008. This pollution data was manually processed in a Microsoft Excel spreadsheet to match the spreadsheet format required for input into i-Tree's back-end database and submitted to the US Forest Service. This data need only be submitted once for each city.

2.3. Weather Data

Weather data was sourced from NIWA's CliFlo online database (NIWA 2013) and manually processed in a spreadsheet to generate a space-delimited text file of the format specified for use in i-Tree Eco. i-Tree requires cloud ceiling, cover and types; visibility distance; weather type codes; pressure; minimum and maximum temperatures; and precipitation (US Forest Service 2013a).

2.4. Field Measurements

Field measurements were performed based on the methods outlined in the i-Tree Eco Manual (US Forest Service 2012a) and advice by Barcham Tree Specialists (Sacre undated). Trees in the Wynyard Quarter case study site (Figure 1) were logged on paper sheets prepared before going on site. An Abney level was used to determine tree height, and tape measures used for height to crown base, crown width in north-south and east-west directions, and diameter at breast height (DBH, which is measured at 1.37 m from the ground). Species, crown light exposure, dieback and percent crown missing were all estimated by visual inspection (Table 1). Trees were photographed and their locations recorded using handheld GPS (Samsung GT-I8190N). Recorded tree locations were later checked against satellite images from Google Maps.

2.5. Valuation of Pollutant Removal

Published and online sources were searched to attempt to identify valuation rates for the removal of all pollutants modelled by i-Tree Eco. These are: CO, O_3, NO_2, SO_2, and particulates (PM_{10} and $PM_{2.5}$). Focus was specifically on NZ-based sources of pollutant removal valuation.

Table 1: Summary of tree field data collected.

Parameter	Measurement	Transforms
Genus, species	Observation	-
Total height	Angle, eye height, distance to tree	Trigonometric
Height to crown base	Angle, eye height, distance to tree	Trigonometric
Number of stems	Count those with DBH >2.54 cm	-
DBH	Circumference	Divide by π
Crown width	Measured N-S and E-W	-
Tree condition	% missing, % dieback	-
Crown light exposure	Observation: 1 to 5 faces exposed	-
Tree status	Observation	-
Street tree?	Observation	-
Land use	Observation	-

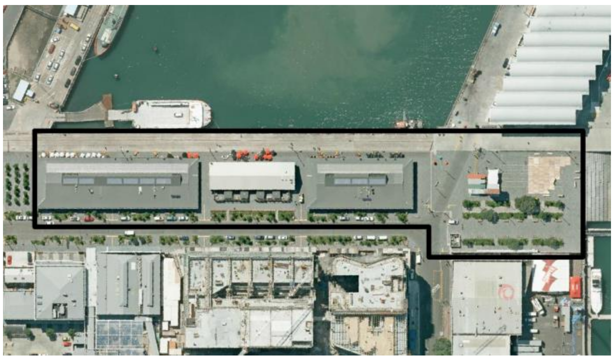

Figure 1: case study site in Wynyard Quarter, Auckland, with study area marked by a black line. Photo courtesy Auckland Council (2013a).

3. Results

A complete inventory i-Tree Eco project was completed for the Wynyard Quarter, Auckland, NZ site and submitted to the US Forest Service for processing. Weather and air pollution data were able to be collated for inclusion in i-Tree Eco, and are now available for future projects. Pollutant valuations were not found for a NZ context, but possible alternatives were located. i-Tree Eco was found to be a useful tool for modelling urban forests in NZ, though some limitations were identified.

3.1. Pollution Data

The Auckland Council air pollution data was sufficient to meet the requirements for inclusion in i-Tree Eco: one full year of hourly data for the pollutants types listed in Table 4. However, a single site was not found for all pollutant types, so four different sites were used. While using multiple sites is not ideal, this appeared to be justified as data points that were common between the sites did not appear to differ greatly, and the data was intended for application anywhere in Auckland. This data was incorporated into i-Tree Eco and is now available for all projects analysing urban trees in Auckland.

3.2. Weather Data

While NIWA's CliFlo database (NIWA 2013) contained weather information from a number of sources around Auckland, no one source could be found with a full year of hourly data for all the required data types that did not have significant omissions. Data was searched across all Auckland sites back as far as 1990, as earlier data was considered likely to not reflect current weather trends and climate changes.

Some data at lower frequencies was available (e.g. on 3-hourly intervals), and collecting data from multiple sites was investigated. Discussion with the i-Tree team at the US Forest Service determined that data from different years would not be suitable (Hoehn *pers. comm*. 2013). However, it was eventually determined that weather data from the National Climatic Data Center (NCDC) (NOAA 2013) in the US had more consistent weather information that could be used for Auckland. This was incorporated into i-Tree Eco by the US Forest Service, so is now available for any future Auckland users.

3.3. Wynyard Quarter Case Study Results

A total of 95 trees were measured, of 7 different NZ-native species (one being a *Metrosideros* hybrid, which was not analysed separately to rata and pohutukawa; species list is shown in Table 2). Nikau were the most common (31), followed by rata and pohutukawa (20 and 9 respectively), the latter two being grouped here as they

Table 2: i-Tree Wynyard Quarter case study results, showing species importance and pollution removal figures. Pollution removal rates in Figure 2 can also be compared with these figures.

Species	n	Leaf Area [m²]		i-Tree Importance
		Total	Per Tree	
Nikau	31	788.0	25.4	33.94
Pohutukawa	9	825.0	91.7	23.19
Rata	20	294.8	14.7	17.12
Puriri	13	175.5	13.5	10.77
Taraire	14	64.9	4.6	8.82
Karaka	8	86.9	10.9	6.15

are closely-related species, and several hybrids existed on this site. Pohutukawa had large effects in the pollutant removal and rainfall interception results, despite only numbering nine trees, as several of these were older and thus significantly larger than the other trees (some mature pohutukawa had been transplanted to the site, while the other trees were only put in when the site was redeveloped in 2011).

Airborne particulate removal by trees is a process that occurs primarily from dry deposition on the leaves (Nowak *et al*. 2002). Thus, the larger the leaf area, the more $PM_{2.5}$ and PM_{10} are removed, as can be seen by comparing Table 3 and Figure 2. Other pollutants were removed more by nikau than by any other species, but simply because these were the most numerous type of tree in the study area. i-Tree Eco assigns an "importance" to tree species (Table 2), a percentage based upon their contributions to ecosystem services in a particular study area. Nikau scored the highest here, due to the high tree count (31), with pohutukawa scoring next-highest, due to the effect of the larger trees.

While the i-Tree Eco Manual states that rainfall interception is an output that is not available outside of the USA (US Forest Service 2012a), i-Tree Eco gave a result of 9.79 m³/year of rainfall intercepted by the trees. Similarly, "tree structural value" was another output that is not expected in an international project, but gave a result of NZD $15,295. Energy effects were not available, as these are based on building standards from the USA, consequently meaning that the input fields for electricity, heating, and carbon costs are irrelevant to NZ projects. Pest analysis was not available, at least for the case study. Extra input data may make this available, however regionally-unique pests would not be listed, though there exists the possibility of working with the US Forest Service to pursue this as an option.

Carbon storage and sequestration are shown in Table 3. Pohutukawa stored more carbon than any other species, again a function of the larger size of these trees. Carbon storage and sequestration is discussed in more detail and compared with NZ biomass equations in a parallel paper by Dale (2013). DBH is a key tree size measurement, but for immature nikau, it was not possible to measure the diameter at the standard height as the main stems did not extend more than about 20 mm above ground level – most nikau in the case study had to be measured at or near ground level. i-Tree Eco is able to adapt its biomass equations for this, with height to DBH being one of the input parameters for each tree.

i-Tree Eco gives analysis down to a specific individual tree, or information grouped by species. A larger project would be able to separate results by location as well. i-Tree Eco takes data entered about the trees, such as percent crown missing and percent dieback to give a qualitative "condition" rating for each tree, from excellent to poor, and then critical, dying or dead (the case study site had only one dead tree, and no others below "fair"). This can be useful for determining the overall status of a tree population.

3.4. Tree Species Information

Taraire (*Beilschmiedia tarairi*) was replaced with *Beilschmiedia miersii* and nikau (*Rhopalostylis sapida*) with *Rhopalostylis baueri*. Two *Metrosideros* species were found in the case study site: pohutukawa (*M. excelsa*) and rata (*M. robusta*), but there were also hybrids of these, which were assigned to either pohutukawa or rata according to which seemed the

Table 3: i-Tree Wynyard Quarter case study results, showing tree characteristics.

Species	Canopy Cover [m²]	Leaf Area [m²]	Leaf Biomass [kg]	Carbon Storage [kg]	Gross Carbon Seq. [kg/year]
Nikau	149.5	788.0	121.7	58.6	0.8
Pohutukawa	200.2	825.0	61.8	1181.4	73.4
Northern Rata	82.3	294.8	22.1	271.8	43.6
Puriri	60.8	175.5	23.5	158.6	29.3
Taraire	15.9	64.9	4.9	41.8	14.2
Karaka	24.2	86.9	6.5	34.7	9.7

closest fit. For the purposes of this paper, these hybrids are not separately examined, however Dale (2013) investigates the hybrids' growth forms and carbon storage separate to the non-hybrid *Metrosideros* species. All other species in the Wynyard Quarter study area existed in the database.

3.5. Valuation of Pollutant Removal

No NZ source for pollutant removal valuations was found, with the exception of CO_2, obtained from current emissions trading prices (Brunel 2013). The Ministry for the Environment have done some research into valuations of pollutants (Ministry for the Environment 2004), but only on concentrations and not the total mass of pollutants, and there does not appear to be a clearly-established method in the literature of converting between these two metrics.

Pollutant valuations in i-Tree Eco projects have typically used the following regression equations, based on US "BenMap" data (Nowak *pers. comm*. 2013b):

$$\mathrm{NO_2}:\ y = 0.6931 + 0.4677\,x \quad (\mathrm{R}^2 = 0.91)$$
$$\mathrm{O_3}:\ y = 9.5011 + 3.5090\,x \quad (\mathrm{R}^2 = 0.86)$$
$$\mathrm{PM_{2.5}}:\ y = 476.91 + 116.75\,x \quad (\mathrm{R}^2 = 0.83)$$
$$\mathrm{SO_2}:\ y = 0.1438 + 0.1910\,x \quad (\mathrm{R}^2 = 0.86)$$

Where x = population [persons/km²].

Additionally, European pollutant valuations were compiled in a report by CE Delft (van Essen et al. 2011), and the values given in this report for the United Kingdom (UK) were in many cases similar to the US-based regression equations (Table 4).

Applying the UK valuations to the i-Tree Eco results from the Wynyard Quarter case study gives total pollutant removal values by these trees of NZD \$246/year, primarily from PM_{10} – valued at NZD \$212/year. $PM_{2.5}$, despite having the highest dollar value per tonne, had negligible effect on the final total due to much lower removal rates compared with the other pollutants (Figure 2).

Table 4: pollutant values. All dollar values have been converted to current NZD. See Section 4.3.1 for comments on the NZ valuation of CO_2.

Pollutant	NZD/Tonne	Country	Source
$PM_{2.5}$	311,007 335,370	UK USA	1 2
PM_{10}	124,319 548	UK USA	1 2
O_3	10,074	USA	2
NOx NO_2	10,847 1,342	UK USA	1 2
SO_2	15,227	UK	1
CO_2 (high) CO_2 (low) CO_2	305 52 1.08	UK UK NZ	2 2 3

Sources: 1: van Essen et al. 2011; 2: Nowak pers. comm. 2013b; 3: Brunel 2013, assuming 27.3% of CO_2 is valued as carbon (% by mass in CO_2).

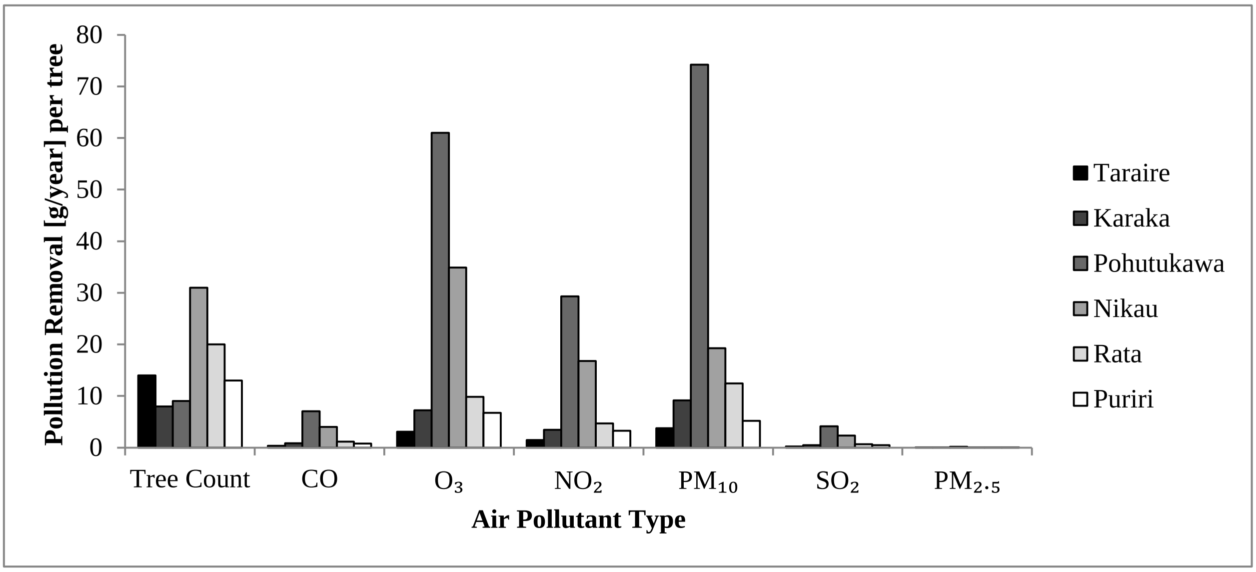

Figure 2: comparisons of pollutant removal rates per tree, by species. Note the large amounts of pollutant removal by pohutukawa compared with other species (considered to be a function primarily of tree size), and the very small reductions in $PM_{2.5}$ relative to PM_{10}.

4. Discussion

4.1. Suitability of i-Tree Eco in NZ

i-Tree Eco seems to be a potentially useful tool for analysing NZ urban trees. Currently, its results can only be considered approximate, with accuracy that is not yet able to be confirmed due to the limited species-specific information and lack of alternative information in the literature related to NZ tree species. There are a number of areas that require further research for i-Tree Eco to become a properly useful tool in NZ.

4.2. Observations from the Case Study

Wynyard Quarter was chosen as a study site as it is a feature development as part of Auckland's City Centre Masterplan (Auckland Council 2013b), and analysis of this project could help guide future urban developments in Auckland. But, due to it only being built recently, most of the trees were immature, which meant that the pollution removals and carbon storage and carbon sequestration rates were much lower than another area with more mature trees. However, this had the advantage of strongly highlighting the differences in pollutant removal of mature and immature trees, by comparisons with the older transplanted pohutukawa (Figure 2).

The value of mature trees has implication for local practice, in that the ecosystem services provided by a well-established tree are far greater than those provided by a small, young tree, so protecting an older tree is of more value than planting new trees. This is not reflected in recent NZ legislation changes, where the Resource Management Act has relaxed rules on the removal of trees (Ministry for the Environment 2013).

Analysis of results from the individual trees did not highlight any obviously incorrect results, but tests to directly determine the validity of results were beyond the resources available to this study. Such checks would have required analyses such as measuring tree functions (e.g. carbon flux), destructive analysis of tree composition, or more detailed studies on tree form and function than are currently available in the literature. However, comparisons between allometric biomass equations results from i-Tree Eco and other extant studies were investigated by Dale (2013). Leaf area equations for NZ tree species is another field of knowledge that is notably lacking at present.

Nikau was a difficult tree form for analysis (Dale 2013), especially where analysis was based on the tree forms of North American hardwoods and softwoods typically used in the forest industry (as is the case with some biomass equations used in i-Tree; Nowak 1996). This may mean that the leaf area and carbon/biomass results for these trees are incorrect, though this is not possible to quantify without further research. Research into the growth and biomass of palms generally would be of benefit to i-Tree Eco users outside of NZ also, although palms do usually have lower wood densities than other tree types (Zanne *et al*. 2009), so are less important for carbon sequestration and storage than many other species.

The structural value result (NZD $15,295 for the case study trees) cannot be reliably used, however it is nonetheless a useful approximate indicator of total tree value. According to the i-Tree Eco Manual, tree structural values are based on methods developed by the Council of Tree and Land Appraisers (CTLA), but are not able to be calculated for international projects (US Forest Service 2012a). Valuation of ecosystem services is a complex endeavour and by necessity is based on a number of assumptions; in this case, it is likely that not all of these assumptions will be valid, but as no breakdown of the calculations is given by the results from i-Tree Eco, there is no way of checking them without consultation with the US Forest Service. Similarly, rainfall interception rates are an unvalidated result and are not easily checked. Rainfall interception rates by different tree species could be measured however, and leaf area to interception rate relationships established, but this is outside the scope of this paper.

4.3. Valuation of Pollutant Removal

On the subject of applying qualitative valuations to ecosystem services, Jim and Chen, (2008: 666) stated, *"The universal language of dollars could facilitate understanding of the otherwise less tangible and important yet widely neglected environmental functions."* Governments and decision-makers communicate in economic terms, so there is a strong case for the importance of being able to apply an economic value to ecosystem services.

i-Tree Eco, if given the appropriate inputs, is able to estimate quantitative dollar values for tree functions such as removing of pollutants from the air. This means that if these values can be found, decision-makers could be supplied with figures that make the value of trees clear in terms they can apply.

While NZ does not appear to have researched dollar-per-mass valuations for air pollutant removal, some work has been done on valuing the concentration of air pollutants, such as in documents used in the development of the Ministry for the Environment's National Environmental Standards for Air Quality (Ministry for the Environment 2004). If a method for equating concentrations and mass removals for a specific location can be found, then this research could be applied directly to quantify tree valuations.

A second option for valuing air pollutant removal is to apply overseas studies, where suitable. To determine the applicability of studies from other countries is not a simple problem, as valuing any ecosystem service is based on a series of assumptions that often vary between location and between different studies. Ecosystem services are "externalities" in an economic sense, in that they do not directly cost – or provide direct economic benefit to – those who are responsible for planting or maintaining them, and many of the benefits trees provide are not directly monetisable, such as their psychological or aesthetic values (Tsunetsugu *et al*. 2013; Costanza *et al*. 1997). The causal chain between a tree's functions and its benefit to a society are often unclear (Aston *et al*. 2008). The benefit of pollutant removal is directly related to population density (van Essen *et al*. 2011), so choosing valuation sources that account for this correctly is important. However, without NZ alternatives, studies such as the US Forest Service's regression equations or the CE Delft study (van Essen *et al.* 2011) provide a starting point for understanding the values of trees.

The total economic value per year of the trees in the case study site appeared small (under $300/year), but it is worth noting that these figures would be higher for locations with more mature trees. Of that total, 39% ($83.02/year) was from the nine pohutukawa, making these more mature trees of at least four times the value at removing pollutants than the average for trees on this site. For even larger trees, these numbers would be higher again.

The pollutant removal value for the case study site was calculated as NZD $2.60 per tree per year. A previous study conducted using i-Tree Eco in Brooklyn, New York calculated a pollutant removal value of USD $1.3 million per year from around 610,000 trees (Nowak *et al*. 2002; this was approximately NZD $1.64 million in 2002). This gives a per-tree pollutant removal value ($2.70 per tree per year) that is very similar to the NZ case study. This suggests that the total pollutant removal value of the urban forest in Auckland is also likely to be worth millions of dollars, primarily in improvements to the health of the city's inhabitants.

4.3.1. Carbon Valuation

The wide differences in the values applied to removing carbon from the atmosphere are highlighted in Table 4 – van Essen *et al*. (2011) gave high and low estimates that differed by almost six times, but even the lower estimate was more than an order of magnitude larger than the current NZ value. While again these are estimates on difficult-to-quantify externalities, carbon now has an actual market value, but the emissions trading markets appear to only have depressed the value of carbon (Brunel 2013).

Liu and Li (2012) calculated the value of carbon storage based on the afforestation cost of trees (cost of removal), adopting a price of USD $41/tonne (NZD $48/tonne) of carbon by dividing the total afforestation costs by the amount of carbon sequestered. This is perhaps a more sensible quantity than the current NZ market value, despite the fact that it does not factor in the environmental impacts of carbon emissions. This suggests it could be a minimum value, and it is in line with the low estimate from van Essen *et al*. (2011).

5. Recommended Future Research

5.1. Weather and Pollution Data

Weather and air pollution data for other NZ cities will need to be sourced if i-Tree Eco is to be used to study trees in other parts of the country. Experience from this project suggests that local council and NIWA data sources should be checked first, with the US Forest Service consulted if data from the NCDC is required. It is unknown if regional or city authorities other than Auckland Council maintain air pollution data, as this study only focused on Auckland.

5.2. Tree Species Information

The accuracy of results from i-Tree Eco would be improved with the development of allometric biomass equations and growth equations for unusual NZ tree species, in particular those with more atypical growth forms, (such as nikau and pohutukawa). Developing leaf area indices for NZ tree species would give more accurate pollutant removal and rainfall interception figures. Both of these can be submitted to the US Forest Service for inclusion in the i-Tree models for all NZ users. As well as improving the accuracy of results, such research would also give opportunity to confirm the validity of outputs related to those species, as current i-Tree Eco outputs are untested for NZ tree species and environments.

5.3. Pollutant Valuations

Economic valuations underpin all central and local government decisions, thus a first step to improving the utility of i-Tree Eco as a tool in NZ would be to determine locally-applicable pollutant valuations. This would give more certainty to the value of trees, and might allow i-Tree Eco to be used to compare possible future planned urban developments. Similarly, determining if the CTLA methods underpinning i-Tree Eco's structural tree value are relevant to NZ would also improve its usefulness.

5.4. Energy Use

In the context of the USA, the i-Tree models are able to be used for analysing building energy use and the effects that trees have on saving energy. At present, this is not available outside of the USA. If energy-related outputs were considered useful to NZ users, close consultation with the US Forest Service would be required to develop NZ-relevant modelling for this to account for local building practices, building standards, and conditions.

5.5. Plot-Based Analysis

This study considered only a full inventory i-Tree Eco project, as a plot-based project, with a recommended minimum of 200 plots, was beyond the resources available. A case study plot-based analysis covering a larger urban area, such as Auckland City, could give results that quantify the city's urban forest as a whole, and improve understanding of i-Tree Eco's large-scale methods for quantifying ecosystem services. Collection of this data could be done in parallel to (or completely separate to) developing the other data requirements for i-Tree Eco, as field measurements are applicable regardless of species.

6. Conclusions

i-Tree Eco now includes weather and pollution data for Auckland, meaning that any future i-Tree Eco projects studying Auckland's urban trees will not need to obtain this data. If a future study is interested only in approximate quantifications and valuations, then i-Tree Eco can be used immediately without needing to submit additional supporting data to the US Forest Service: only the field data needs to be sent.

i-Tree Eco's potential for analysing and quantifying the ecosystem services of urban trees has the potential to provide great benefit to NZ cities. However, further research is needed if its accuracy is to be properly validated, and for it to be able to quantify the effects on ecosystem services of using different species.

While the pollutant removal value of a single tree is low, the cumulative effect of urban trees – especially mature ones – in a city such as Auckland could be in the millions of dollars. Thus, investment in further research into the valuation of urban trees is recommended.

Acknowledgements

The student would like to thank his project partner Meredith Dale for her work and inspiration, his supervisor Dr Elizabeth Fassman-Beck for her support and constructive critique, his second examiner Dr Carol Boyle, Dr David Nowak (i-Tree Team Leader) and Robert Hoehn of the US Forest Service. Thanks also go to Dr Neil Mitchell and Luitgard Schwendenmann of the University of Auckland, Adrien Bouzonville of Tonkin and Taylor for supplying pollution data, and Shanju Xie and Karen Creagh from Auckland Council for their assistance. Specific thanks go to Auckland Council and NIWA for allowing re-use of their data by the US Forest Service.

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